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CLIMATOLOGY IN THE SERVICE OF AGRICULTURE

by

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CLIMATOLOGY IN THE SERVICE OF AGRICULTURE

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Abstract

For more than a century climatology in the United States has worked in the service of agriculture. However, during the last several decades the principal support has gone to meteorology for the purpose of making daily weather forecasts and agricultural climatology has not kept pace with other agricultural sciences. The great need is for more intensive study of climatic conditions immediately surrounding cultivated plants, for laboratory studies to give an exact evaluation of the effect of the different climatic factors, and for new statistical and graphical techniques for determining the relation between climate and agriculture. This is not a task for the climatologist alone nor for the biologist alone, but for the two working in collaboration. The work of the climatologist must be coordinated with that of the chemist, the physiological botanist, and other agricultural scientists.

It is now just a half century, lacking 1 year, since the International Meteorological Congress met in Chicago in connection with the World's Columbian Exposition. On that occasion, Professor Liberty Hyde Bailey, one of the most influential agriculturists in the United States during the last generation, presented one of the addresses under the title "Some Interrelations of Climatology and Horticulture." Professor Bailey commenced his address with the observation that "Climatology concerns the agriculturist in two general directions--in aiding him to anticipate the condition of the weather some hours or days and thereby enabling him to plan his work with confidence, and in explaining the climate of any place in such a manner that he can determine its probable influence upon a prospective business." Thus we have in Professor Bailey's statement a foreshadowing of the two topics posed for consideration on this occasion: the economic value of weather forecasting in crop production and the economic relationship of climate and agriculture.

These topics representing, respectively, the contributions of meteorology and climatology to agriculture are the logical outgrowth of the development of the two sister sciences. The influence of climate on the distribution of vegetation and of crops has been recognized for centuries; and in the absence of actual instrumental measurements climates have been named after their characteristic vegetation. The terms "forest," "steppe," and "desert" have long been used as names of types of climate as well as of types of vegetation. As meteorological instruments were developed and systematic climatic observations began to accumulate, the possibility of stating explicity the relationship that exists between the climatic elements that were being measured and various features of agriculture seemed about to be realized.

It was with the aim of rendering assistance to agriculture that the first organized system of climatologic observations in the United States was inaugurated in 1817, by the Commissioner-General of the Land Office. Two years later the Surgeon-General of the Army initiated systematic observations of temperature, rainfall, and air pressure at military posts throughout the country. This was at a time when it was believed that climate was a direct cause of disease. The observations were made as a part of a program to safeguard the health of troops being stationed at newly established Army posts on the frontier in the unsettled and largely unexplored interior of our continent. To this early interest in medical climatology we owe the few long weather records that exist in the vast country west of the Appalachians. The Patent Office in 1841, and the Smithsonion Institution in 1847, inaugurated systems of organized observations.

Interest in weather observations arose from agricultural and medical climatology. Lorin Blodget's great work, "Climatology of the United States...", was published in 1857. It demonstrated a growing awareness of the importance of climatic studies to agriculture. The bulk of the book deals with climatic hazards and limitations to the agricultural development of the western half of the United States that was then awaiting settlement. There are also important sections on the climatology of staple crops, cereals, and grasses.

Almost as soon as weather observations began to be available for a large number of places in the eastern part of the United States the study of individual storms commenced. In 1834 a joint committee of the American Philosophical Society and the Franklin Institute sought "means of promoting the advancement of Meteorology" and with the assistance of a corps of volunteer observers began to accumulate information on the size, form, and rate and direction of travel of storms. James Espy, the Chairman of the Joint Committee, published his "Philosophy of Storms" in 1841. Espy and others observed and established the progressive movement of atmospheric disturbances from west to east or from southwest to northeast, and pointed out the possibility of forecasting the approach of such disturbances. The invention of the telegraph made it possible to bring together quickly weather observations made simultaneously at a number of places, and led to a tremendous interest in the possibilities of daily weather forecasting. The first published forecasts, based on telegraphic observations, were made by Joseph Henry of the Smithsonian Institution in 1849. These forecasts were made daily until the outbreak of the Civil War in 1861.

The practical importance of accurate daily weather forecasts was easy to grasp, and gradually interest in synoptic meteorology came to surpass that in climatology. In 1870 a Federal Weather Service was established in the Signal Office of the U. S. Army. The publication of a daily weather map commenced in that year. Although daily weather forecasting was the primary interest of the Weather Service, the usefulnessof climatology to agriculture was appreciated, and reports on the climate of various parts of the West, then in process of being settled, were prepared and published.

The great potential value to agriculture of the climatological activities of the Federal Weather Service was clearly recognized, and in 1891 the Weather Service was transferred to the Department of Agriculture and became

Weather Bureau. In the Act effecting the transfer the duties of the Chief were defined. He was to "have charge of the forecasting of the weather," and also of "the taking of such meteoroligical observations as may be necessary to establish and record the climatic conditions of the United States..."

Within the first few years of its existance the Weather Bureau published a number of monumental works on various phases of agricultural climatology: e.g., "A Report on the Relations of Soil to Climate," by E. W. Hilgard; "Some Physical Properties of Soils in Their Relation to Moisture and Crop Distribution," by Milton Whitney; "Report on the Climatology of the Cotton Plant," by P. H. Mell; and "A First Report on the Relations between Climates and Crops," by Cleveland Abbe. These works are necessarily general but point out lines for more detailed work.

Other Governmental agencies were also interested in climate as it affects agriculture. In 1894, C. Hart Merriam, Chief of the Biological Survey, published a work entitled "Life Zones and Crop Zones of the United States." In the letter of transmittal accompanying this work he said:

> It is hoped that this report, with its accompanying zone map and crop lists, will serve to emphasize the extreme wastefulness of indiscriminate experimentation, by which hundreds of thousands of dollars are thrown away each year in futile attempts to make crops grow in areas totally unfitted for their cultivation.

In the summary of this work Merriam made a strong claim for the practical value of his climatic scheme:

> It appears, therefore, that in its broader aspects the study of the geographic distribution of life in North America is completed. The primary regions and their principal subdivisions have been mapped, the problems involved in the control of distribution have been solved, and the laws themselves have been formulated.

Such an extreme statement could not help but arouse suspicion, because it is obvious that no study is ever "completed" and no problems are ever "solved." Furthermore, it was easy to discover that Merriam's scheme did not give the insight into the relations between climate and vegetation that was being sought.

Abbe's "Report on the Relations of Climates and Crops" was written in 1891, the year in which the Weather Bureau was established in the Department of Agriculture. It was not published, however, until 1905. This delay demonstrates a declining interest in agricultural climatology in the Weather Bureau. In recent years, after a brief revival in the decade 1916-1925, official work in the United States Weather Bureau has been directed away from agricultural climatology almost entirely and more and more exclusively toward the improvement of weather forecasting. After the transfer of the Weather Bureau to the Department of Commerce in 1940 there was no longer in the Department of Agriculture an agency whose business it is to cultivate climatology in connection with agricultural problems.

The field of climatology that most closely approaches weather forecasting and that supplements it and that is of great potential importance to agriculture is the examination of climatologic data from the viewpoint of the theory of probability. The power of this technique has long been recognized. In fact, an excellent illustration of it appeared in the Patent Office Report on Agriculture for 1855 in a communication by Joseph Henry under the title "Meteorology in its Connection with Agriculture." He said:

> No one knows the day nor hour of his own death, and nothing is more entirely uncertain than, in a given case of expected birth, whether a boy or a girl shall be born; but the number out of a million of men living together, in one country, who shall die in ten, twenty, forty or sixty years, and the number of boys and girls who shall be born in a million of births, may be predicted from statistical data with almost unerring precision... It is this regularity which is observed in phenomena, when studied in groups of large numbers, which enables us to arrive at reliable and permanent laws in regard to meteorology...and which furnishes the basis, in accordance with the principles of assurance, a knowledge of what species of plant or animal may be profitably raised in a given locality.

We could state the probability that the tenth of July will fall on Sunday as 1/7, because we know that a week consists of 7 days and that each day is equally likely. There is no need to restrict our statement in this way, however, because we can easily refer to a calendar and thereby determine that it is certain to fall on Sunday or certain not to as the case may be; that is, we can make a positive forecast. To say that the probability of next tenth of July falling on Sunday is 1/7 is a useful statement only so long as we remain in ignorance of when it really falls.

We might, again, have wished to know some time ago whether it would rain tomorrow, and if so, how much. This is a question that no one could answer with certainty a month ago, nor can it be answered with complete assurance even today. Rainy and sunny days do not follow each other in a set pattern as do the days of the week; they are not related to a calendar, but are instead functions of the general circulation of the atmosphere. The weather sequences at an observing station result from changes in the direction and velocity of the wind, and in the properties of the air brought in from first one and then another direction. These changes are in turn consequent on the large-scale turbulence of the atmospheric circulation, which, as the meteorologists are discovering, has the statistical quality of randomness. Every turbulence element has inertia, however, and so tends to retain its direction and speed of motion. This is the quality of the circulation that makes weather forecasting by synoptic procedures possible. The inability to say with certainty whether or not it will rain tomorrow makes it desirable to state the probability of various amounts of rain.

There is obviously no reason to expect that various possible amounts of rain are equally likely, as are the days of the week. In fact it is evident

that very large amounts are less likely than moderate amounts; perhaps clear days are more likely than rainy days. The only way in which the probability of rain on July 10th can be determined is through analysis of past observations. For Mexico City, D. F., and Washington, D. C., the probabilities are approximately as follows:

	Mexico City	Washington
No rain	.246	.679
Rain in any amount	.754	.321
2.5 mm. (.10 inches) or more	.482	.206
6.3 mm. (.25 ") " "	.314	.134
12.7 " (.50 ") " "	.121	.083
25.4 " (1.00 ") " "	.039	.037
38.1 " (1.50 ") " "	.004	.021
50.8 " (2.00 ") " "	-	.010

These values do not tell us what will happen on July 10th any more than the fraction .143 (1/7) tells us whether that day will fall on Sunday. They do tell us that at Washington we can expect rain on July 10th only about 3 years out of 10, whereas at Mexico City it is to be expected 3 years out of 4. A rain of 25 mm. (1.00 inch) or more is equally probable at both places and may be expected about once in 25 years, but a rain of 50 mm. (2.00 inches) or more can be expected not oftener than once a century in Washington and very much less often in Mexico City.

Climatological analysis of past records will give valuable insight into the expectation of rainfall during the period of the present conference. In Washington it has rained as many as 9 of the 11 days in the period July 6-16. At the other extreme, in 1890 there was no rain between July 6 and 16. In Mexico City there have been years when it rained every day in this 11-day period, but in 1914 there were only 3 rainy days in it. A record of 40 years at Mexico City gives us the following information about rain in the period July 6-16:

No. of rainy days	No. of experiences
11	2
10	4
9	9
8	7
7	9
6	4
5	3
4	1
3	1
2	0
1	0
0	0

This table does not constitute a forecast and does not guarantee that there will be rain during our conference. It does, however, strongly suggest that we should be prepared for at least 7 days in which rain can be expected. The expectation of rainy days in Washington at this time is considerably less, but the near certainty of very hot weather in Washington, in contrast to mild temperatures in Mexico City, is an added reason why the members of the Washington delegation are grateful for the selection of Mexico City as the site of the conference.

It is perhaps of no great importance to agriculture to know the probability of various amounts of rain on a particular day; but a knowledge of the changing probability from day to day throughout the year, or of the changing probability of droughts of various lengths, or of any other climatic hazard to agriculture, can be of very great value in adjusting and revising the schedule of various farming operations. For example, the soil erosion hazard is directly proportional to the probability of intense rain; thus, to ensure a permanent agriculture the land should not be stripped of its crop cover at a time of high probability of intense rainfall.

Probability analysis is only one of the various lines of research applicable to agricultural climatology. In a single sentence of the preface of his "Report on the Relations between Climate and Crops" Professor Abbe referred to several others:

> The very extensive problem suggested by the title of this report involves, first, a general study of meteorology in its relations to vegetable and animal life; second, the determination of the effect of climate upon the growth and distribution of staple crops; third, the determination of the climatic conditions and the localities best suited to the growth of special varieties of plants and seeds; fourth, the statistics of the extent of the areas best adapted to each of the more important crops; fifth, the separate and the combined effects of temperature, rainfall, and sunshine, both in their normal and abnormal proportions, upon the annual yields of the staple crops... Three ways are generally recognized as affording our only method of advancing our knowledge of our subject, viz., physiological, experimental, and statistical. I shall therefore endeavor to present the question of climates and crops from these three points of view.

In fulfilling its obligation "to establish and record the climatic conditions of the United States," the Weather Bureau has had to standardize its instruments and the manner in which they are exposed as well as the type of observation and the form of statistical presentation. Agricultural specialists have usually tried to make use of these regular climatologic observations but too often have found that they do not, except on rare occasions, provide answers to questions that arise in relation to agricultural production. For example, the climatic elements that affect different crops in different parts of the country differ, and in order to measure critical values of the elements special observational nets are required. The climatic relations of growing plants that are in fact important slip readily through the meshes of the existing net of climatologic stations.

Entomologists have been seeking the climatic factors that control the distribution and spread of the European corn borer in the United States. This study is of great economic significance because the correct delimitation of the climatic range of the insect would permit the relaxation of a costly quarantine. The entomologists know intutitively that climate and weather are the principal factors responsible for the distribution and spread of the insect, but they have failed to find a significant relation. The climatological data available to them are the familiar observations made at a city station of the Weather Bureau. Daily or monthly totals of rainfall and daily and monthly means of temperature at a location perhaps miles away surely have little to do with the state of health of the corn borer. Clearly the important features of the environment are the temperature and moisture regimes of the atmosphere just where the eggs, larvae, and the mature insects are. The moisture and temperature requirements of the insect in all stages of its development must be determined through laboratory study; and then the climatic observations needed are presumably measurements of temperature and moisture all the way from the roots of the corn to its tassels.

At the same time the agronomists have been searching for the relation between climate and the yield of corn. Here, too, it is clear that the temperature and moisture regimes are exceedingly important factors. Nevertheless, attempts to relate corn yield to the values of temperature and precipitation that are regularly measured have, for the most part, been unsuccessful. These instrumental observations do not define the critical elements for corn yield. The minimum requirements for the purpose would seem to be detailed observations of temperature and moisture from the root zone in the soil to the ends of the tassels.

The need for additional instrumental and phenological observations has been stated many times in the past. Particularly has it been emphasized that there must be more intensive study of climatic conditions immediately surrounding cultivated plants, including light as well as temperature and moisture. Usually the plea for more observations is accompanied by a most vague statement of the statistical techniques to be used in their analysis. The discovery has been made repeatedly that little that is not already known intutitively about the relations between the various elements of climate and crop yields can be learned by familiar methods of simple correlation.

Multiplicity of observations could easily lead to greater confusion instead of to clarification. Not only are new systems of observation required that are especially designed for individual problems; in addition new methods of statistical analysis must be developed in order that the desired results may be obtained from the observational data. If laboratory study can tell what are the optimum values of the various environmental factors at every stage in the life history of the organism, it should then be possible to determine the deviations of the actual climate from the optimum and to arrive at an integrated value of the total effect of the climate throughout the season. Such a program would necessitate the grouping of climatic observations according to the various critical phases in the life cycle of the organism rather than according to the civil calendar.

A single system of climatic observations might suffice in the study of corn yield and of the insect enemies of corn; but it is virtually certain that each problem would require its individual statistical analysis, since different organisms have different life cycles and climatic optima.

Each problem clearly requires study from the climatic as well as from the biologic side. Special exposure of instruments, sometimes the construction of special instruments, always the special handling of observational data are required. The job is not one for the biologist alone nor for the climatologist alone, but for both in collaboration. To that collaboration the biologist can bring his previous knowledge of the organism and his techniques for obtaining more knowledge about it. The climatologist can bring knowledge of how temperature and humidity vary within distances that are small in relation to ordinary meteorologic observation but significant to a plant or an insect; of how instruments may be installed and if necessary constructed so as to give the observational data needed; and of how these data may be handled so as to yield the maximum of insight. The major task is to coordinate the work of the climatologist with that of the chemist, the physiologist, the ecologist, and others.

As we all know, we face a desperate shortage of rubber. Every possible means of making up the deficiency is being explored; and at present chemists are working on so-called synthetic rubber and plant scientists on sources of natural rubber for the Western Hemisphere. The fact that a substance like rubber can be fabricated from oil, natural gas, coal, and alcohol distilled from farm crops does not reduce the importance of the natural product from plants, or release us from the responsibility of developing new supplies of natural rubber just as rapidly as possible. Two developments show promise, plantation rubber in tropical America and guayule in arid and semi-arid America, but in both of these programs an adequate climatological analysis might save much time and expense.

Guayule is a native of the States of Chihuahua, Coahuila, and Durango in Mexico, and occupies in the United States of America only a small area across the Rio Grande in south Texas. This is a region of semiarid climate in which there is a summer maximum of rainfall. The plant has, however, been introduced into semiarid coastal California, where rainfall is limited to the winter season. Strains of guayule that have been developed in the summer dry climate at Salinas, California, produce in the neighborhood of 16 percent of rubber, but the yield drops to 5 or 6 percent when they are grown in Arizona, New Mexico, and Texas. This experience demonstrates that the amount of rubber synthesized within the guayule plant depends on the regime of rainfall and drought as it relates to the temperature regime. It would appear that a drought rest stage in the warm season favors the accumulation of rubber more than one in the cold season.

The immediate problem is to determine the areas in which guayule plantings should be made during the present and the next season. Until the physiological requirements of the plant are better known, this problem involves simply the delimitation of the localities that have climates

identical with or at least closely similar to the climate of the place where it is most successfully grown at present. This procedure involves the rather naive assumption that the climate of Salinas, California, is the best that can be found for guayule production. Moreover, since the area having a climate identical with that of Salinas is limited, certain assumptions must be made concerning the nature and extent of variations in the temperature and moisture regimes that are permissible in climates that may still be considered "similar." Frequency distributions of the maximum temperatures of summer and of the minimum temperatures of winter and similar analyses of various aspects of the moisture regime at various stations will help to show the extent to which various areas differ in climate from Salinas. Incidentally, it is of interest to note that the climate of Santiago, Chile, is as near like that of Salinas, California, as any climate could be.

If records of growth and production of guayule in individual years and detailed observations of the local climate were available it would certainly be possible to establish the climatic limits of the plant with some precision. It might be possible in addition to forecast the percentage of rubber content that could be expected in various climatic regions. Solution of this problem may involve micro-climatic field observations as well as statistical analysis of existing data from the various meteorological offices; and it may assure greater rubber production at less cost. This problem is not one for any single specialist; it clearly requires collaboration of the chemist, the physiologist, the pedologist, and the climatologist. It is an unhappy fact, however, that the climatologist is not a member of this team.

Agricultural climatologists are too few. There is at present no systematic attack on the problems of agricultural climatology and nowhere is there any adequate formal training for climatologists. I believe it is fair to say that the need for agricultural climatology has been demonstrated through the years, and that if this field of scientific endeavor were encouraged by agricultural institutions it would quickly develop and in the course of time would serve agriculture faithfully and well.